Decentralized Guidance, Navigation, and Control for Platoons of Cooperating UUVs

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LONG-TERM GOALS

Our long-term goals are to develop and implement theoretically justified, yet practical, navigation and control algorithms required for deployment of platoons of cooperating unmanned underwater vehicles.

OBJECTIVES

The objectives of this effort are to develop: (1) control synthesis methods for control algorithms that can be distributed among a platoon of UUVs with minimal inter-vehicle communication requirements, (2) centralized control algorithms that are easily synthesized, generate multi-objective behaviors for a platoon of vehicles, and may potentially be distributed among a platoon of UUVs, (3) decentralized control algorithms that permit high accuracy "group navigation" despite low accuracy sensors.

APPROACH

Our approach is two-fold. First, we are developing theoretically-justified control algorithms for UUVs and demonstrating their effectiveness via computer simulation. Second, we are building a platoon of very simple and inexpensive ground-based mobile robots for hardware-based verification of our results. Throughout, limited communication constraints are a primary focus.

Our work on control algorithm development is based on the notion of decentralized fixed modes [2], [9]. Using this approach, we are able to propose a candidate communications network and determine if a stabilizing controller exists that can be decentralized among vehicles in a platoon. Once a suitable network has been found, we seek efficient methods of synthesizing the decentralized controller. For example, we have examined the network topology shown in Figure 1 and shown that the total communications bandwidth is independent of the number of vehicles in the platoon. This property

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15. SUBJECT TERMS

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permits platoons composed of larger numbers of vehicles to be controlled despite the limited underwater communication channel. Details of this network and related networks are available in [7] and [8].

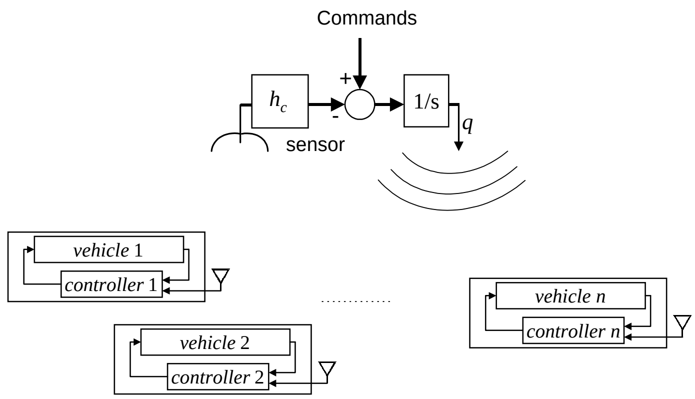

Figure 1. Block-diagram of a communications network topology for a platoon of UUVs. [An exogenous sensor is shown along with a platoon of UUVs. The exogenous sensor measures features of the platoon that are to be regulated, integrates the measurements, and broadcasts them to the platoon. Each vehicle implements a local controller whose inputs are locally generated information and the signal broadcast from the exogenous sensor.]

In a related effort, we seek to demonstrate achievable platoon-level objectives using techniques from redundant manipulator control [3] applied to the multi-robot problem, as discussed in [6]. Through these studies, we will invesitgate the types of platoon missions that can potentially be achieved with complete centralization, which will provide a limiting case for the decentralized approach and will form the basis for future decentralized controller synthesis tasks.

WORK COMPLETED

Our project has only recently begun, and all work is ongoing. A control synthesis technique suitable for UUV platoons has been developed and will be essential for addressing questions related to group navigation. Initial studies on platoon formation synthesis using centralized techniques have been completed, forming the basis for a new approach to platoon control that addresses issues of optimal deployment and optimal path planning for various objectives.

Acquisition of components for ground-based hardware experiments has begun.

An initial project on single-vehicle inertial navigation has been completed. We examined the utility of nonlinear observers for rapid calibration and alignment of a 3-axis rate-gyro [5]. This work was a first step toward the group navigation problem.

RESULTS

Results thus far include the development of an efficient control synthesis technique for the communications network shown in Figure 1. The importance of this results is in the fact that decentralized control synthesis is generally considered to be NP-hard [1]. Loosely speaking, this implies that efficient algorithms for designing a decentralized controller do not exist. Indeed, recent published work concerning the network in Figure 1 indicates that the control synthesis remained an open problem [8]. With an efficient control synthesis method available, other properties of this network and related networks can be investigated, including the group navigation problem.

Additionally, studies on centralized control of platoons using redundant manipulator techniques have offered fundamental insight into the nature of the real-time platoon formation synthesis problem. We have demonstrated that casting the platoon control problem in this framework allows for efficient platoon formation control in an unknown environment under multiple objectives. This new approach to the problem suggests that platoon control may benefit from standard robotic control techniques, and forms an important step toward understanding potential applications of our decentralized work.

IMPACT/APPLICATIONS

This work has broad applicability in the field of autonomous vehicles. Decentralized techniques are fundamental to efficient utilization of multiple vehicle deployments, especially in the underwater theatre where communication is a substantial bottleneck. Indeed, many algorithms designed for ground and air applications are not applicable underwater due to communication constraints. Our work on centralized techniques has similar applicability for networked vehicle platoons and offers a new perspective on the cooperation, formation synthesis and planning problems.

TRANSITIONS

None to date. Implementation of our results on for two micro AUVs is under discussion: (1) USNA-2, a second generation micro-AUV under development at the United States Naval Academy (see [4] and Figure 2); (2) the Ranger micro-AUV, under development by Nekton Research, LLC.

Figure 2. USNA-1, a micro autonomous underwater vehicle designed at the U. S. Naval Academy for experiments in controlling platoons of underwater vehicles.

RELATED PROJECTS

Closely related on-going projects include,

1. Development of nonlinear observers for rapid alignment and calibration of UUV navigation sensors, with Professor Louis Whitcomb, Mechanical Engineering Department, Johns Hopkins University

2. Design of practical micro-AUVs, with Carl Wick, Systems Engineering Department, United States Naval Academy (see Figure 2).

3. Design of gliding AUV body shapes by teams of Midshipmen at the United States Naval Academy with support of the Academy's Model Shop and Hydromechanics Laboratory.

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